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Characterization of two electrode systems for corona-charging of non-woven filter media

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ABSTRACT

The aim of this paper is to provide a better understanding of the corona-charging process of non-woven electret filters for automotive and medical applications. The experiments were performed on polypropylene samples: 500-μm-thick non-woven fabrics (fiber diameter: 24 μm), laid on a grounded plate electrode and subjected to positive or negative corona generated either by a dual wire–cylinder electrode or by a triode-type electrode set. The paper reports the results of current–voltage characteristics measurements, as well as the repartition of the current density at the surface of the grounded electrode.

1. Introduction

The presence of electric charges at the surface of insulating materials can cause electrostatic hazards in industrial processes, as it may endanger both the operator and the electric and electronic equipment employed [1–4]. In many applications, such as the manipulation of textile materials, paper sheets or polymeric films, the electric forces associated with these charges can make the materials stick to each other or to be grounded on metallic surfaces [5,6]. Electrical discharges from charged items represent a major hazard source in the manufacturing process of electronic devices [7,8].

However, there are many other industrial processes (photocopying, electrostatic spraying, electrostatic separation, etc.) where the electric charging of insulating materials is a highly-desirable phenomenon. This is also the case of fibrous filtration media manufacturing [9,10], which most often consist of non-woven polymeric fibers. The numerous studies carried out in the last decades proved the highly improved filtration proprieties of these media due to the electric charge [11–17]. The electrically-charged fibrous media are particularly effective for collecting particles smaller than 3 μm in diameter. The filtration efficiency depends on the strength of the electric field as seen by the particle, which is determined by the charge and charge distribution on the fiber. The persistency of this charge both at the surface and in the volume of the media is a prerequisite of high filtration efficiency [18].

Corona discharge is the most frequently used method for the electric charging of the filtration media. This can be generated between two asymmetric electrodes, one energized at a DC high-voltage (HV) source (metallic pins, blade(s) or wire(s)) and the other one is grounded (metallic cylinder of plate). There are several types of electrodes employed in industry, such as dual wire–cylinder electrode, pins–cylinder electrode, blade–cylinder electrode, point electrode. In many cases, electrode configurations based on metal wires energized from DC high-voltage supplies commonly serve as corona electrodes and are considered the most appropriate ones to be used in many applications [19,20]. There are some cases when triode-type electrode arrangements are employed, to better control the value of the charging potential at the sample's surface [21,22].

Some observations on the corona-charging characteristics of a non-woven polypropylene (PP) fabrics used for manufacturing the filtration media are reported in Ref. [21]. That study as well as those performed by other researchers on various corona-charged

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fabrics [23–25] suggests that the limitation of the electric potential at the surface of the samples is caused by the back corona phenomenon. Horenstein [25] used a pin-plate electrode arrangement to charge woven fabrics and put into evidence the back corona by comparing the current–voltage characteristics obtained with and without the samples at the surface of the grounded electrode.

A similar approach was adopted in the present paper, with the aim to characterize a dual wire–cylinder corona electrode and a triode-type electrode arrangement as charging devices for non-woven PP fabrics. In addition to the plot of the respective current–voltage characteristics, the experimental set-up enabled the measurement of the repartition of the corona current density at the grounded electrode, which makes possible an evaluation of the charging zone extension on the surface of the samples.

2. Samples

The experiments were conducted on two types of flat samples, denoted by S1 (Fig. 1) and S2 with the geometrical dimensions of 170 × 120 mm^2. The S1 samples consist of non-woven polypropylene fabrics (sample thickness: $g_{S1} = 350$ μm; fiber diameter: 24 μm; mass $m_{S1} = 0.66$ g; average volume fill fraction: 20%). The S2 samples are PP films of thickness $g_{S2} = 90$ μm, mass $m_{S2} = 4.16$ g.

3. Experimental set-ups

3.1. Current–voltage characteristics

In the first set of measurements, the electric charging of the samples was performed using a dual wire–cylinder corona electrode [26] (Fig. 2). The active element was a tungsten wire (3, Fig. 2) (diameter $d_w = 0.2$ mm) suspended from a metallic cylinder (2, Fig. 2) (diameter $d_c = 26$ mm) by two metallic rods (4, Fig. 2). The wire was situated at $h_{cw} = 34$ mm from the metallic cylinder's symmetric axis and at $h_{wp} = 30$ mm from the grounded metallic plate (6, Fig. 2). The length of the tungsten wire was $L_w = 112$ mm. The electrode system was energized from a high-voltage source (1, Fig. 2) (model SL 300, SPELLMAN). The samples (5, Fig. 2) were in contact with the grounded plate. The electric current was measured using a Keithley 6514 pico-ammeter (8, Fig. 2) connected between the metallic plate and the ground connection. The instrument has several ranges between 2 nA and 20 mA and the accuracy varies between 0.4% + 400 fA (within the 2 nA range) and 0.1% + 1 μA (for the 20 mA range).

The triode set-up consists mainly of the same elements, the only difference being the metallic grid (11, Fig. 3) located between the tungsten wire and the grounded aluminium plate. The metallic grid consists of rhombic form loops with the e axis 1.5 times longer than the f axis (Fig. 4). The distance between the metallic grid and the grounded plate is $h_{gp} = 15$ mm. The grid is connected to the ground through a variable resistance R (9, Fig. 3) and a micro-ammeter (10, Fig. 3). The role of the grid is to impose a given potential V_s (and hence a uniform charge) at the surface of the sample ($V_s = V_g$) [11].

The electric current I_g through this resistor R establishes the potential V_g between the grid and the plate electrode at a value $V_g = R \cdot I_g$. The current I_g is a fraction of the current I_s of the corona discharge generated between the tungsten wire and the grid. During this type of measurements, the variable resistance R was adjusted between 10 and 70 MΩ. The measured physical quantities were the charging potential V provided by the DC HV source, the electric current I_g that passes through the variable resistance R and the current I at the plate surface (with and without sample) during the corona discharge process.

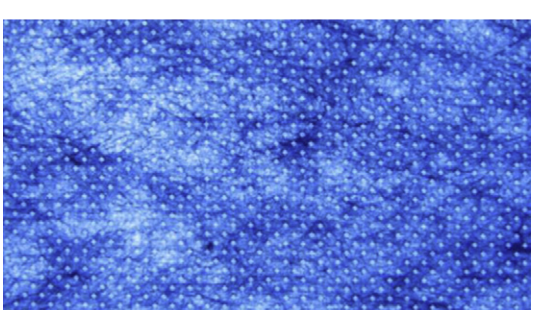

Fig. 1. S1 sample made of non-woven fibrous filter medium.

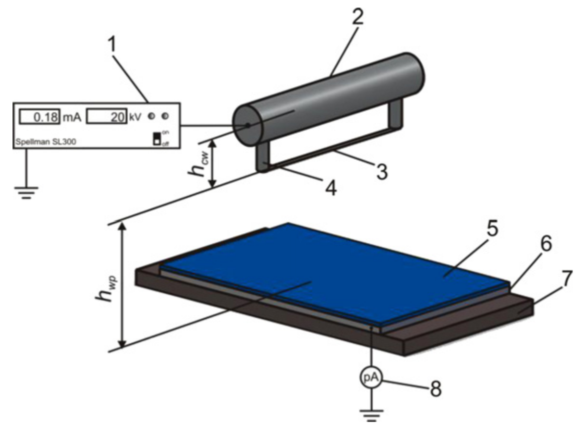

Fig. 2. Experimental set-up for the measurement of the current–voltage characteristics of the dual wire–cylinder electrode employed for the charging of PP non-woven samples: 1 – DC HV source; 2 – metallic cylinder; 3 – tungsten wire; 4 – metallic rods for sustaining the wire; 5 – sample; 6 – grounded metallic plate (grounded electrode); 7 – PVC support; 8 – pico-ammeter; h_{cw} and h_{wp} – geometric distances.

3.2. Current density repartition

In the second set of experiments, the current density in different areas of the grounded electrode was measured using a special designed printed circuit board (PCB) plate with seven strip current probes disposed as shown in Fig. 5. The strips are electrical isolated from each other and from the rest of the PCB.

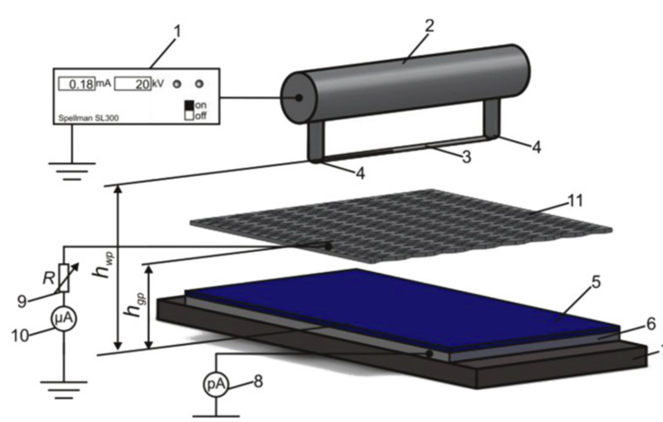

Fig. 3. Experimental set-up for the measurement of the current–voltage characteristics of the triode electrodes system employed for the charging of PP non-woven samples: 1 – DC HV source; 2 – metallic cylinder; 3 – tungsten wire; 4 – metallic rods for sustaining the wire; 5 – sample; 6 – grounded metallic plate (electrode); 7 – PVC support; 8 – pico-ammeter; 9 – variable resistance; 10 – micro-ammeter; 11 – metallic grid; h_{wp} and h_{gp} – geometric distances.